Jochen Jirmann, DB 1 NV

A FM-Transceiver for 10 GHz with dielelectrically-stabilized Oscillator

The GaAs-FET doubler module FO-DP12, or FO-DP13 described in the previous edition of VHF COMMUNICATIONS (1) is especially suitable for construction of a small 10 GHz transceiver for wideband FM. The current drain of the dielectrically-stabilized oscillator is three to four times less than that of a Gunn oscillator with straight-through mixer; this is a great advantage for portable operation.

Table 1 gives the specifications of the transceiver:

Microwave module:	FO-DP12 or FO-DP13
Frequency range:	10.25–10.45 GHz
Operating mode:	Wideband FM, frequency shift 105 MHz or 30 MHz, according to IF
Transmit power:	4–5 mW
Noise figure:	Approx. 12–15 dB (comparable with a Gunnplexer)
Operating voltage:	12 V / 150 mA

The dimensions of the compact, author's prototype **(Figure 1)** are 150 × 120 × 55 mm; the total weight of 800 g also includes an accumulator with a capacity of 225 mAh, which is sufficient for one hour's operation, without external power sources.

The transceiver comprises the following modules: A modified doubler module FO-DP12KF, or FO-DP13KF, an IF/AF-module, the voltage stabilizer for the FET-oscillator, and a modulation amplifier complete with dot generator.

1. DOUBLER MODULE

As has already been described, the FET-oscillator tuned to 10.525 GHz is provided with one or two mixer diodes, which are used as straight-through mixer. For amateur applications, it is necessary for the frequency to be pulled into the amateur band and for the fixed tuning to be made variable. This is achieved by modifying the module as follows:

The cover complete with the tuning screw can be removed after carefully bending up the tabs. The ceramic laminate on which the microwave circuit is built up should not be touched! It is now possible for the tuning screw to be replaced by a miniature micrometer, or by a M5-screw with a fine thread together with a matching bushing.

Attention should be paid that no play is present; this is also valid when using a Gunn

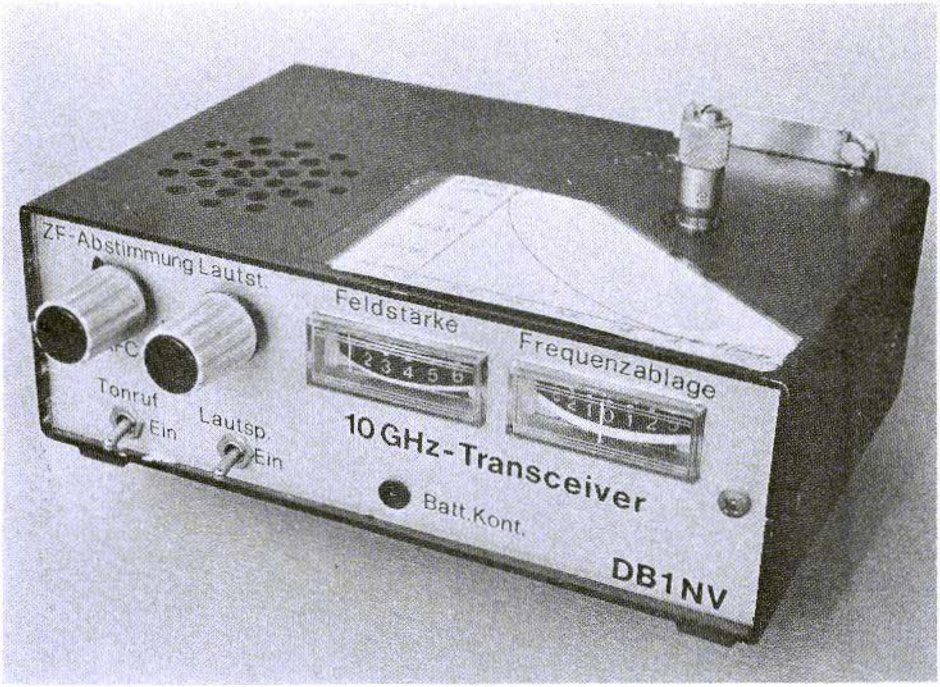

Fig. 1: The 10 GHz FM-transceiver described by the author

oscillator. The cover then is replaced and soldered around the edge with the aid of a large soldering iron **(Figure 2)**. The tuning can now be made with the aid of an absorption wavemeter **(Figure 3)**.

Finally, a tip: Since FETs and mixer diodes are very sensitive to static charge, it is important that all connections of the module are connected to the case until they are installed into place.

2. IF-AMPLIFIER

A large number of IF-circuits have been described for 10 GHz transceivers. These, however, have all required additional modules such as preamplifiers, squelches, AFC-modules, etc. The IF-circuit to be described does not require any external modules, only the external controls, and its dimensions are very compact (72 mm x 145 mm). The module can also be used as 144 MHz FM-receiver by changing a few components.

The IF-module is designed for a frequency of 105 MHz, but can also be modified for 30 MHz. However, in this case one must expect a 1 to 2 dB inferior system noise figure, since part of the noise sidebands of the microwave oscillator will be converted back to IF-level. Considering the large number of 30 MHz-systems operating in conjunction with Gunn oscillators, it is surprising that this is not common knowledge.

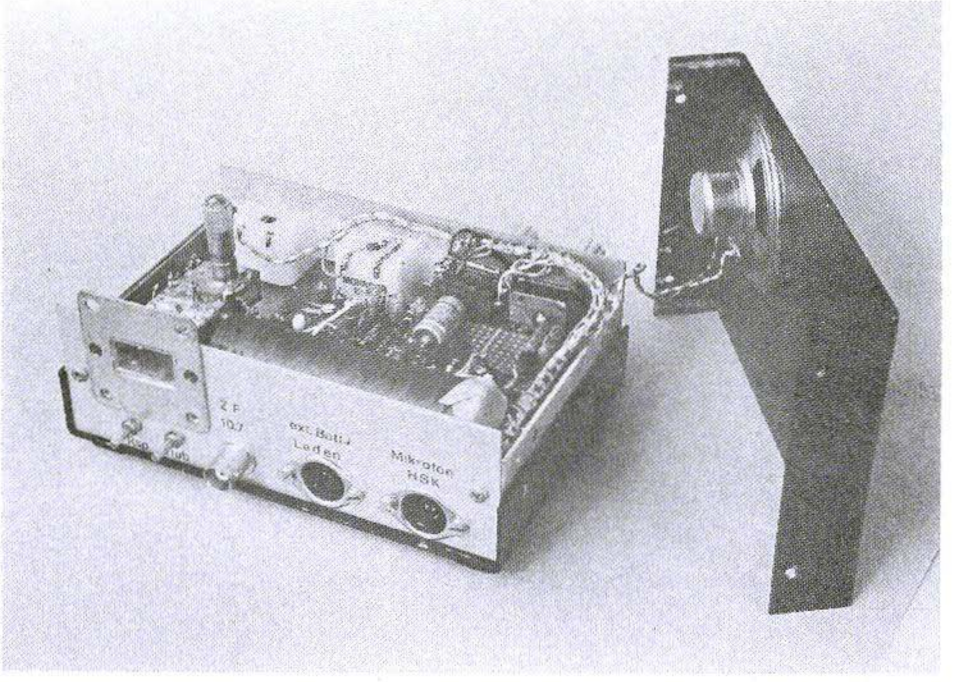

Fig. 2: Voltage stabilizer for the oscillator, as well as the modulator are built up on Vero boards in the author's prototype

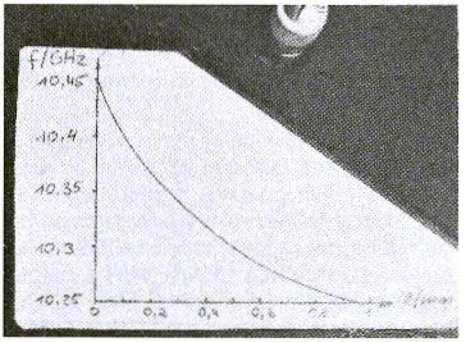

Fig. 3: The calibrated scale of the transceiver

2.1. Concept

The module operates at an intermediate frequency of 105 MHz, and can be tuned electronically by ± 1 MHz. The input is designed for direct connection to a conventional mixer diode (IF-impedance approx. 300 Ω). The noise figure of the IF-circuit is better than 2 dB. In order to increase the sensitivity of the receiver further, the IF-bandwidth was reduced to 100 kHz, and a lowpass filter having a cutoff frequency of 3 kHz, and a slope of 18 dB/octave was provided in the audio amplifier.

The automatic fine tuning operates at the intermediate frequency of 105 MHz. This solves all problems with respect to the control direction of the AFC, which is required when controlling the microwave oscillator.

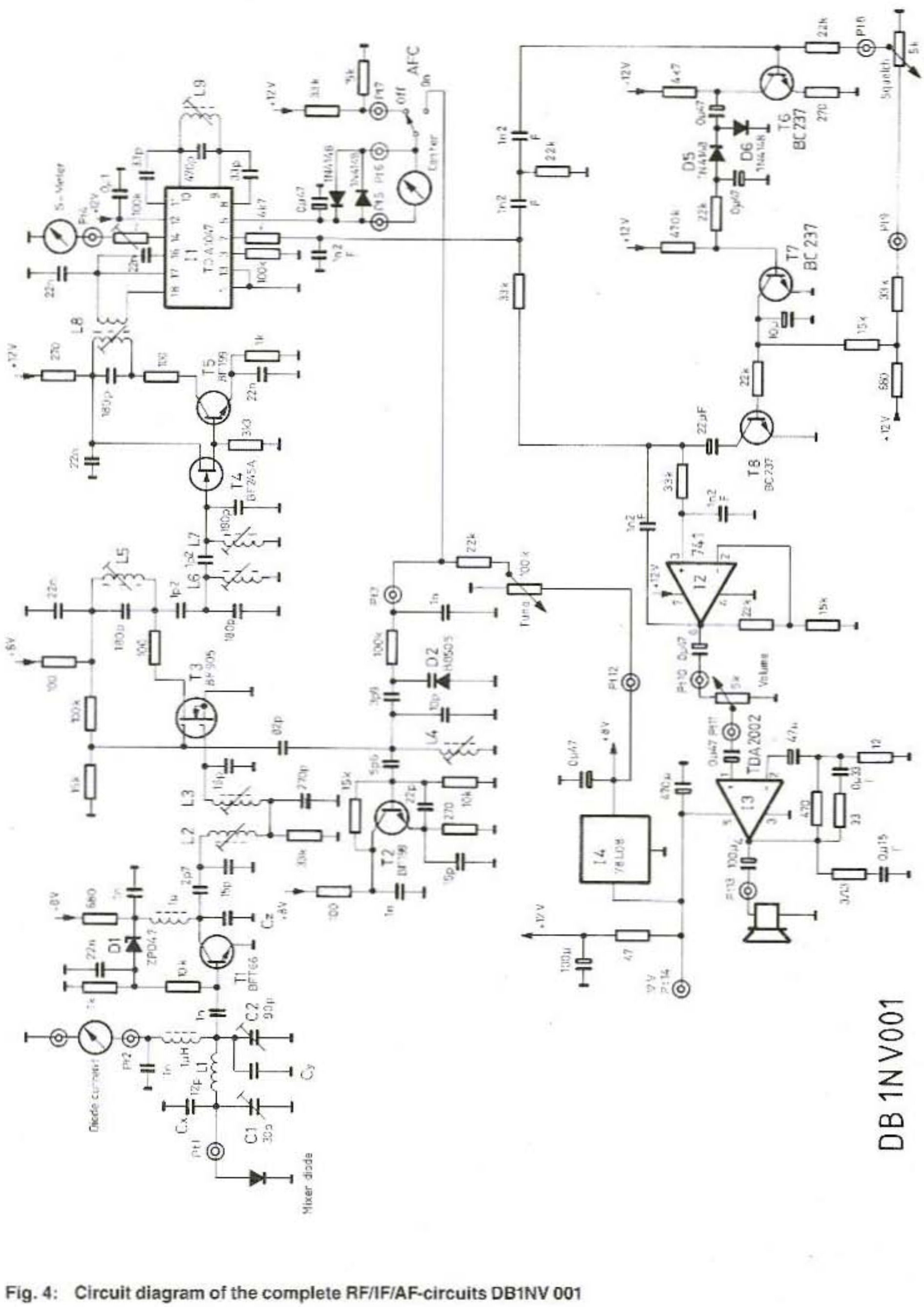

Fig. 4: Circuit diagram of the complete RF/IF/AF-circuits DB1NV 001

The tuning range of max. 1 MHz is sufficient if the microwave oscillators are relatively stable. The circuit possesses a squelch using the conventional 8 kHz method, and is provided with an efficient AF-amplifier **(Figure 4)**.

2.2. Circuit Description

The mixer diode of the microwave circuit is connected with the aid of a short piece of coaxial cable (max. 10 cm) to the input of the IF-amplifier. The variable network comprising L 1 and the two trimmers C 1 and C 2 transforms the impedance of the diode (approx. 300 Ω) to the input impedance of the preamplifier transistor T 1 (BFT 66). The real component of the input impedance is approximately 80 Ω. A meter for monitoring the diode current can be connected to Pt 2. If this is not required, Pt 2 should be grounded. The operating point of the BFT 66 is stabilized with the aid of a zener diode to $U_{CE} = 6\ V/I_C = 3\ mA$.

The preamplifier is followed by a two-stage bandpass filter. The bandwidth of the filter is in the order of 2 MHz, and the coupling is slightly overcritical. The subsequent mixer stage equipped with a dualgate MOSFET BF 905 converts the 105 MHz ±1 MHz-signal to the second intermediate frequency of 10.7 MHz. The local oscillator equipped with a BF 199, oscillates at 115.7 ±1 MHz and is tuned with the aid of a varactor diode BB 505. A voltage of 1 to 8 V at Pt 3 is necessary to cover the whole tuning range. VHF-preamplifier, mixer, and oscillator are operated from a stabilized voltage of 8 V from a 78 LO8. This voltage is available at pin 12 for further applications (e.g. transmit modulator).

The main selectivity of the IF-circuit is made in the LC-filter following the mixer. This three-stage filter is undercritically coupled, and possesses a bandwidth of approximately 100 kHz, which is the ideal bandwidth for a wideband FM-signal having a frequency deviation of 40 to 50 kHz, and a maximum modulation frequency of 3 kHz. The PC-board is designed so that a 10.7 MHz crystal filter (such as QF 10.7–30) can be installed instead of L 6 and L 7. This allows the module to also be used for narrow-band FM-systems, and as a FM-receiver for 144 MHz.

The matching amplifier equipped with T 4 (BF 245) and T 5 (BF 199) amplifies the 10.7 MHz-level to a level over that of the wideband noise generated in the FM-demodulator. An integrated circuit TDA 1047 is used for FM-demodulation, generation of the control voltage and tuning voltage.

The internal squelch of this integrated circuit is designed for broadcast applications and will not open until the signal is in excess of S9 when receiving amateur transmissions. For this reason, it was switched off by grounding pin 13. The internal AFC-switching is also not used (pin 2 remains disconnected). The phase-shift circuit for the FM-demodulator is tuned with the aid of L 9. An S-meter with a dynamic range of 50 dB can be connected to Pt 4. The AFC-output of the TDA 1047, pin 5, is a push-pull current source, which can supply or accept a maximum of 150 μA. This allows the AFC-circuit to be connected in parallel with the normal tuning voltage. As long as no frequency shift is present, the AFC-output will "float" together with the tuning voltage. The maximum hold range of the AFC is determined by the impedance of the tuning voltage source. In the circuit used here, the AFC-current is fed via the center-zerometer (±50 μA) either to the tuning diode of the oscillator, or when the AFC is switched off, to a voltage divider that is provided to ensure the correct operating point for the center-zerometer. Since many 10 GHz-stations only possess one meter which is switchable to S-meter and center-zero indication, two antiphase diodes are connected between Pt 5 and Pt 6; these secure the AFC-current path when the center-zerometer is switched off.

The demodulated signal from pin 7 of the TDA 1047 is passed through a lowpass filter (cutoff frequency = 12 kHz) for suppression of any residual IF, and is fed via a 33 kΩ resistor to the active AF-filter, and via a highpass filter (cutoff frequency = 6 kHz) to the noise amplifier T 6, which is equipped with a BC 237. After rectification of the noise, the resulting voltage is fed via a switching transistor (T 7) which controls

the AF-switch T 8 (BC 237). The coupling from the collector of the switching transistor to the squelch potentiometer generates the necessary hysteris for optimum switching characteristics.

The operational amplifier I 2 (LM 741), and the AF-power amplifier I 3 (TDA 2002) form a Butterworth-lowpass filter with a cutoff frequency of 3 kHz and a slope of 18 dB/octave with the aid of their associated components. Any loudspeaker of at least 2 Ω impedance can be connected to the output.

2.3. Measured Results

Operating voltage range:	10–16 V
Current drain:	approx. 80 mA
VHF-bandwidth:	2 MHz
IF-bandwidth:	approx. 100 kHz
Noise figure:	< 2 dB
AF-output:	max. 5 W

2.4. Components

T 1:	BFT 66 (Siemens) possibly BFT 97 (pay attention to case!)
T 2, T 5:	BF 199, BF 241
T 3:	BF 900, BF 905 (Texas Instr.)
T 4:	BF 245 A (Texas Instr., Siemens)
T 6...T 8:	BC 237, BC 413, BC 550, or similar
D 1:	ZPD 4, 7 or C4V7 or similar zener diode
D 2:	BB 105, BB 505
D 3 – D 6:	1 N 4148 or similar
I 1:	TDA 1047 (Siemens)
I 2:	741, DIP 8
I 3:	TDA 2002 (SGS, Telefunken)
I 4:	LM 78 L08 (National), possibly 7808
L 1:	4.5 turns of 1 mm dia. silver-plated copper wire wound on a 5 mm former, self-supporting
L 2 – L 4:	4.5 turns of 0.5 mm dia. enamelled copper wire in a special coil set, 10 x 10 x 15 mm; yellow core
L 5 – L 7:	20 turns of 0.25 mm dia. enamelled copper wire in a special coil set, 10 x 10 x 15 mm; yellow or blue core
L 8:	20 turns + 6 turns, otherwise as L 5
L 9:	9 turns, otherwise as L 5 RFC: 2 miniature chokes 1 μH
C 1:	30 pF plastic foil trimmer, 7.5 mm dia. (Philips, red)
C 2:	90 pF plastic foil trimmer, 10 mm dia. (Philips, red). Other capacitors: Ceramic capacitors, min. 5 mm spacing.
Exceptions:	5 plastic foil capacitors, 1.2 nF, spacing 7.5 mm 1 plastic foil capacitor of 0.15 μF and 0.33 μF resp., spacing 7.5 mm.

Other bypass capacitors (22 nF, and 0 μ1): Ceramic tubular or multilayer capacitors.

Small electrolytics: Tantalum, or aluminium. Loudspeaker coupling electrolytic and bypass electrolytic for the operating voltage: Aluminium electrolytics, for horizontal mounting, 16 V, spacing 22.5 or 30 mm.

All resistors for 10 mm spacing.

2.5 Construction and Alignment

The circuit is accommodated on a double-coated PC-board (see **Figure 5**) whose dimensions are 70 mm x 144 mm. The PC-board has been designated DB1NV001. It is designed to be accommodated in a metal box of 72 x 145 x 25 mm. The upper side of the PC-board is in the form of a ground surface, and those components holes that are not grounded should be drilled out in the conventional manner **(Fig. 6)**. Attention should be paid to the manufacturing tolerances of the FETs T 4 (BF 245) during construction. A voltage of approximately 0.7 to 1.5 V must be present at the emitter of the BF 199 (T 5), otherwise it will be necessary to try another FET.

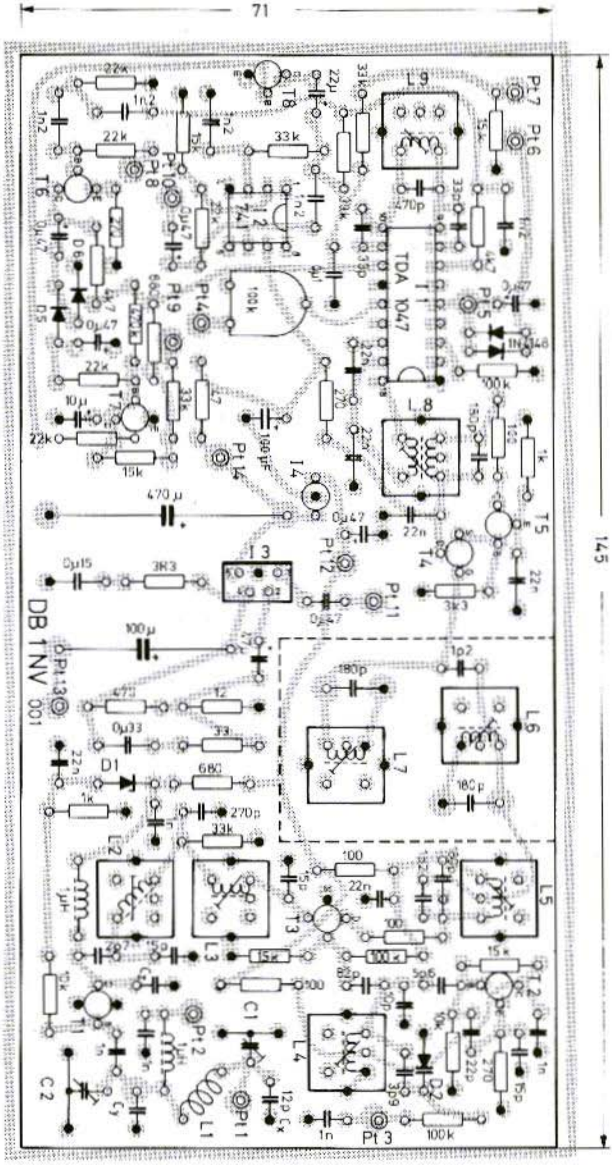

Fig. 5:
Component locations on the double-coated PC-board DB1NV 001

Point marked ● are to be soldered at both sides.

The integrated AF-amplifier is very advantageous due to its internal shortcircuit, overload, and over-temperature protection, as well as due to the low number of external components required; however, it possesses large manufacturing tolerances with respect to its quiescent current. One should select one having the lowest current drain. If the AF-amplifier oscillates, try and change the Boucherot-link (3.3 Ω/0.15 μF). The TDA 2002 need not be provided with a heat sink for normal output power levels.

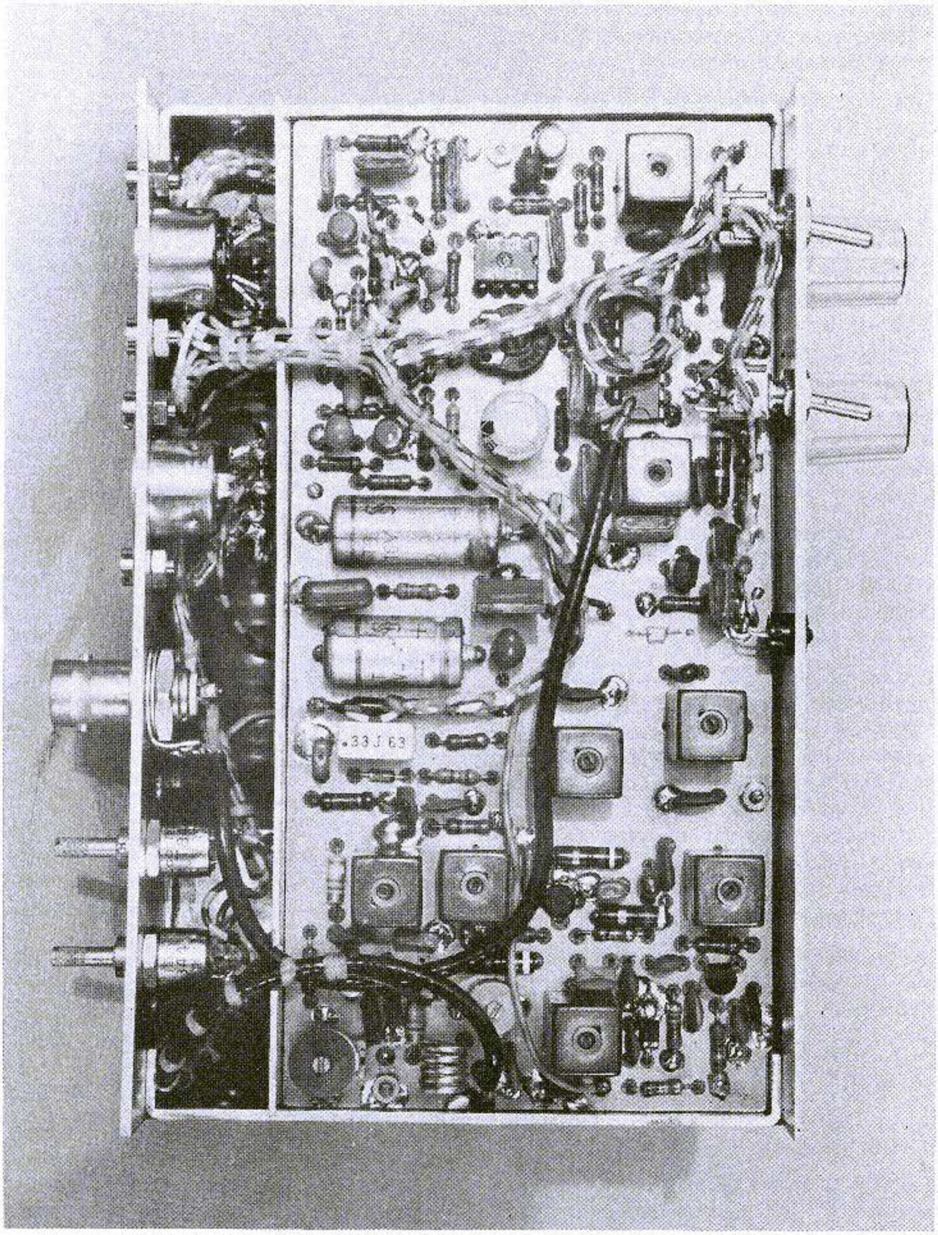

Fig. 6:
Photograph of the completed module DB1NV 001

The following are required for alignment: Multimeter, frequency meter, and a signal source for 105 MHz and 10.7 MHz.

Firstly check the voltage, directly after switching on, at Pt 12 (+8 V), as well as at the emitter of T 5 (+0.7 to 1.5 V), and at the collector of T 1 (+ 6 V).

Pt 4 is now connected to a suitable S-meter (e.g. 100 μA full scale), and a 10.7 MHz signal is fed to the gate of T 4. Inductances L 8 and L 9 are now aligned for maximum S-meter reading (the demodulator circuit including L 9 has a great effect on the S-meter).

The 10.7 MHz-signal is now fed to gate 1 of T 3; align L 5, L 6, and L 7 for maximum reading. A center-zero meter can now be connected between point 5 and 7, and inductance L 9 is aligned for zero.

This is followed by aligning the oscillator with the aid of L 4 to a center frequency of 115.7 MHz. The tuning range should amount to approximately 2 MHz when varying the voltage at Pt 3 from 1 V to 8 V.

The output of the 105 MHz signal source is now connected to the input via a resistor of 270 Ω. The signal generator should be terminated with 68 Ω. Align L 2, L 3, C 1, and C 2 for maximum S-meter reading. The trimmers C 1 and C 2 should be aligned later for best signal-to-noise ratio of the 10 GHz signal. If a swept-frequency generator is available, it is possible to subsequently align the filter comprising L 2/ L 3 to obtain a balanced passband curve.

No alignments are required in conjunction with the audio circuit, and it should operate immediately. The completed board is shown in **Figure 7**.

2.6 Modifications

If module DB1NV001 is to be used in conjunction with a lower input frequency than 105 MHz, the capacitance range of trimmers C 1 and C 2 of the input filter will not be large enough. For this reason, space has been provided for connecting two parallel capacitors,

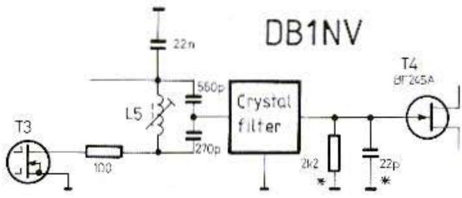

Fig. 7:
Circuit modification when using a crystal filter in the 10.7 MHz IF. The two components marked with * are mounted on the lower side of the board.

which are designated C_x and C_y in the component location plan.

If a tendency to oscillation is noticed in the input stage, it is possible for a capacitor (C_z in the component location plan) to be connected from the collector of T 1 to ground. The required value (a few pF) should be found experimentally.

It is also possible for the IF-filter comprising L 6 and L 7 to be replaced by a crystal filter such as the QF 10.7–30, when the module is to be used as a narrow-band FM-receiver. Some slight modifications must be made to the circuit:

The drain circuit of the mixer (L 5) transforms the output impedance of the DG-FET to the input impedance of the crystal filter of approx. 2.2 kΩ. The output of the crystal filter is also terminated with 2.2 kΩ/30 pF. If the passband curve can be swept, a 30 pF trimmer should be used instead of the fixed 22 pF capacitor, and aligned for minimum ripple in the passband range. **Figure 8** shows the required modifications when using a crystal filter.

When using the previously mentioned 30 kHz crystal filter in the IF, it is possible for module DB1NV001 to be used as miniature receiver for 145 MHz, if the input circuits are modified to this frequency. If the audio output is to be increased when receiving narrowband FM, the demodulator circuit of the TDA 1047/L 9 can be modified as described in (2).

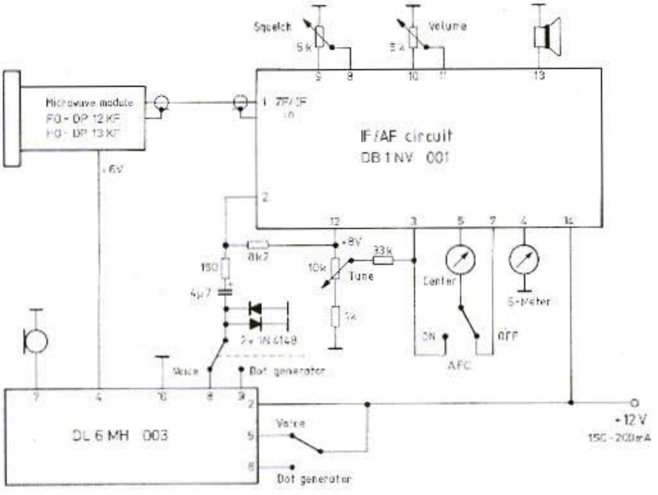

Fig. 8: Block diagram of the complete 10 GHz transceiver.

3. OTHER MODULES REQUIRED FOR TRANSCEIVE OPERATION

3.1. Voltage Stabilizer for the Oscillator

The FET-oscillator does not place any great demands on the supply voltage source. Any control circuit can be used that can supply 6 V at 50 mA. The simplest method is to use a fixed voltage stabilizer 7806, or 78L06.

3.2. Modulator

No reproducible results are obtained when modulating the frequency with the aid of the operating voltage, as is often the case with Gunn oscillators. Furthermore, the AM-component is very high. A far better solution is to modulate the externally impressed bias current for the mixer diode (0.5–1 mA); in this manner, it is possible to obtain a maximum frequency deviation of 200 kHz with a negligible AM-component. Any audio amplifier can be used as modulator, that can provide a voltage of 1 V_{pp} into 200 Ω. The author used a simple, two-stage audio amplifier with diode clipper, and a CMOS-oscillator as keyed sinewave oscillator (dot generator).

It is also possible to use module DL6MH 003. The voltage stabilizer provided on this board can be adjusted to 6 V, and will provide the supply voltage for the FET. A capacitor of 0.22 µF should be connected from pin 1 and pin 3 of the 7805 to ground in order to suppress any tendency to oscillation of this integrated voltage stabilizer.

4. INTERCONNECTION OF THE MODULES

The individual modules are interconnected as shown in **Figure 9**. Attention should be paid to the following: The IF-cable from the microwave module to the IF-amplifier should be kept as short as possible (max. 5 cm), otherwise, it

will not be possible to match it to the mixer diode. When using module FO-DP12 KF, one selects the diode that provides the highest IF-level, and the other diode is left open-circuit. If voltage peaks appear at the output of the AF-amplifier on switching on and off, it is necessary to provide the protection diodes shown in the circuit diagram. These are provided to limit the voltages appearing across the mixer diode to permissible values.

After completing the construction, align the FET-supply voltage to 6 V. It is possible with the aid of a weak 10 GHz signal for the matching to the mixer diode to be optimized. After this, the transceiver is ready for operation.

5. REFERENCES

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